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MODULATION OF THE X-RAY FLUXES BY THE ACCRETION-EJECTION INSTABILITY

Varnière, P.[1], Muno, M.[2], Tagger, M.[3] and Frank, A[4]

Abstract. The Accretion-Ejection Instability (AEI) has been proposed to explain the low frequency Quasi-Periodic Oscillation (QPO) observed in low-mass X-Ray Binaries. Its frequency, typically a fraction of the Keplerian frequency at the disk inner radius, is in the right range indicated by observations. With numerical simulation we will show how this instability is able to produce a modulation of the X-ray flux and what are the characteristic of this modulation. More simulations are required, especially 3D MHD simulations. We will briefly present a new code in development: AstroBear which will allow us to create synthetic spectra.

1 Introduction: a brief presentation of the AEI and relation to observation

The Accretion-Ejection Instability [5] is a spiral instability similar to the galactic spiral but driven by magnetic stress instead of self-gravity. This instability affects the inner region of the disk when the plasma $\beta = 8\pi p/B^2$ is of the order of one, i.e. there is equipartition between the gas and magnetic pressure. It forms a quasi-steady spiral pattern rotating in the disk at a frequency of the order of a few times the orbital frequency at the inner edge of the disk. This spiral density wave is coupled with a Rossby vortex it creates at the corotation radii (corotation between the spiral wave and the gas in the diks). This coupling permits the energy and angular momentum to be stored at the corotation radius allowing accretion to proceed in the inner part of the disk. Contrary to MRI based accretion models the AEI does not heat-up the disk as the energy is transported by waves and not deposited locally.

The Rossby vortex twists the foot points of the field liness. In the presence of a low density corona this torsion will propagate as an Alfven wave transporting energy and angular momentum store in the vortex. This will put energy into the

[1] University of Rochester, Department of Physics & Astronomy
[2] MIT
[3] SAp, CEA/Saclay
[4] University of Rochester, Department of Physics & Astronomy

corona where it might power a wind or a jet [7].

In order to apply the AEI to the phenomena occuring in microquasars we have two observables that we used: the presence of jet; thecharacteristic of the Quasi-Periodic Oscillation (QPO). We already have compared some of the properties of the AEI with observations, mainly the relation between the inner radius of the disk from spectral fit and the QPO frequency [3], [6]. This leads us to try to compare more QPO characteristics with the observations.

2 AEI and QPO

In order to compare the AEI to observations we aim to produce synthetic spectra from numerical simulation. We used the code presented in [2] and add an energy equation to compute the heating of the disk at spiral shocks. The idea was to use the spiral shock to heat the disk and create a thicknenning along the spiral. Using an hydrostatic approxmation to compute the local thickness of the disk we get the inner region of the accretion disk appears as in figure 1. We see that along the spiral arm the disk gets thicker (the z coordinates) and hotter (the color scale) than other locations in the disk.

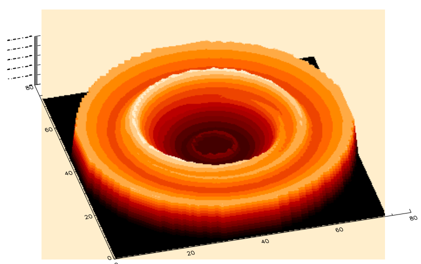

Fig. 1. Snapshot of the inner disk, the heigh represent the local thickness of the disk and the color represent the temperature (lighter color meaning higher temperature)

In collaboration with M.Muno we have computed the X-ray flux coming from such an accretion disk. We obtain a modulation of the observed flux. This modulation is coming from geometrical effect related to the inclination angle of the source such as seen on the left graph of figure 2.

We see that the rms amplitude ($\sim 5\%$) is too small to explain the observations (as much as 20% sometimes). Several phenomena could increase the observed rms amplitude of the modulation. Indeed, the simulation did not take into account relativistic effects. Another effect is the fact that the disk thickness is computed as posteriori and not evolve in the simulation. The hydrostatic equilibrium is a good "first approximation" and allows us to prove that the AEI is able to modulate the X-ray fluxes but in order to compare with observation we need simulations of the disk taking into account the three dimensions.

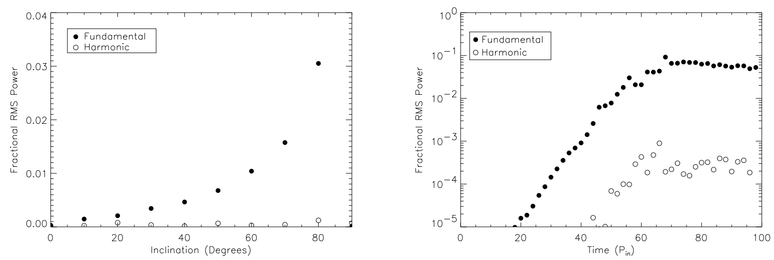

Fig. 2. left: maximun rms amplitude obtain for different inclination of the system. right: evolution of the rms amplitude of the modulation as function of time.

3 A New 3D MHD AMR code: AstroBear

Numerical simulation is a tool which allows us to study phenomena and also to compare theory with observation by the mean of synthetic observation/spectra in their non-linear behaviour. If we want to study in more detail the accretion and ejection we need to have a 3D MHD code. Including Adaptativ Mesh Refinement (AMR) in the code will allow us to have a good resolution with less numerical cost. Using AMR is not always useful depending on the phenomena study, i.e. AMR is not interesting for turbulence but it will be really useful to study jet's knots or spiral waves.

We are working on such a 3D AMR MHD code using a Godunov-type methods for the base scheme. This method projects the solution of the eigenfunction of the Riemann problem associated.

Astro-Bear use a package called BEARCLAW. BEARCLAW is a general purpose software package for solving time dependent partial differential equations (automatic adaptive mesh refinement, parallel execution). AstroBear is a module meant for astrophysical purpose, especially the accretion-ejection phenomena. At the moment the hydrodynamics module fully operationnal in 3D and we are testing the MHD.

We have done the standard 1D MHD test to check the ability of the code to resolve each waves. When going to 2D one needs to take care of the divergence of the magnetic field. Several method exist currently in AstroBear we utilize three of them, the 8th-waves, the GLM and the projection method. Our interest is to find the one that is the most adapted depending on the problem we want to solve. We will also add the choice between several Riemann solver, each of them having different weakness and strength.

In figure 3 show two standard 2D tests. On the left is a cloud-shock interaction where a shock wave propagates through a media having a high density cloud in it. To do this test we used the 8th-waves method for the divergence constraint. This method does not "clean" the divergence mkdir at each step but advect it with the

flow. It does not required a new step but add the non-vanishing divergence term in the source step. It is the fastest method and well adapted. The figure on the

Fig. 3. 2D test of the MHD solver with two differents method for the divergence. left: a cloud-shock interaction using the 8-waves method. right:the Orzag & Tang vortex using the projection method.

right is the Orzag & Tang vortex. This time we have used the projection method in order to "clean" the divergence at each time step. This method requires us to solve a Poisson equation and cost a lot in term of efficiency.

4 conclusion

Using numerical simulation we gave the proof of principle that the AEI is able to modulate the X-ray flux and we aim to continue this study by creating synthetic spectra which can be directly compare with observation.

In order to do this we need a code able to fully simulate an accretion disk. We have done the first step toward this goal by developing and testing the MHD module of AstroBear.

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